Estimating Crop Residue Cover by Blue Fluorescence Imaging

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*C*rop residues, the portion of the crop left in the field after harvest, can be an important management factor in controlling soil erosion. Current methods for quantifying crop residue cover use tedious manual sampling methods or visual comparisons with photographs. There is a need for new methods to quantify residue cover that are rapid, accurate, and objective. Scenes with known amounts of crop residue were illuminated in the lab with long-wave ultraviolet (UV) radiation and fluorescence images were measured and recorded with a video camera equipped with a mico-channel-plate image intensifier and fitted with a 453–488 nm bandpass filter. Six agricultural soils were used as backgrounds for the weathered soybean residue. Residue cover was determined from the proportion of the pixels in the image with fluorescence values greater than a threshold. Soil pixels gave the lowest fluorescence or brightness responses in the images and the residues the highest, so that brightness values of the scene spanned nearly the full range of the 8-bit video data. The images were classified in brightness categories that related to within 2% (absolute units) of measured residue cover regardless of the soil type or moisture condition (dry vs. wet). Therefore, fluorescence images can be used to provide percent residue cover in the lab, but portable equipment and procedures for use in the field still need to be developed. ©Elsevier Science Inc., 1997

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INTRODUCTION

Fifty million hectares or one-third of U.S. cropland is classified as highly erodible land (USDA, 1991). Crop residues, the portion of the crop left in the field after harvest, can be an important factor in conserving soil and water. As little as 30% residue cover on the soil surface can significantly reduce soil erosion compared with bare soil (Alberts and Neibling, 1994). Consequently, accurate crop residue cover measurements help evaluate the effectiveness of conservation tillage practices. Crop residues also affect hydrologic and surface energy balance processes (Steiner et al., 1994).

Although many methods of measuring vegetation cover have been described in the literature (Bonham, 1989), only the intercept and photographic techniques are appropriate for measuring crop residue cover in the field (Laflen et al., 1981). Intercept techniques determine the presence or absence of residue at a finite number of points. The line-point transect (or line-transect) method is the current standard technique used by the Natural Resources Conservation Service (NRCS; formerly the Soil Conservation Service, SCS) to measure residue cover (Morrison et al., 1993; 1995). Accuracy of the line-transect depends on the length of the line and the number of points used. Typically, at least 500 points must be observed to estimate corn residue cover to within 15% of the mean (Laflen et al., 1981). Morrison et al. (1995) evaluated nine modifications of the line-transect method and found that the variation among trained observers for the same device obscured detailed performance comparisons among the nine devices. Because a large source of variation among the methods is associated with the human observer, researchers have often recommended replacing visual measurements with

sensor-based devices to obtain the consistently objective measurements required to achieve the desired precision in estimates of residue cover (McMurtrey et al., 1993; Morrison et al., 1993).

Photographic techniques analyze photographs or images using manual or computer-aided methods to identify and classify residues and soils. Errors occur when the spectral differences between classed (i.e., soil and residue) are not sufficiently large for discrimination (Meyer et al., 1988; Morrison and Chichester, 1991). Corak et al. (1993) used manual editing procedures to improve discrimination of soil and residue.

Spectral Reflectance

Until recently, all sensor-based devices to measure crop residue cover have relied on measuring reflected radiation. In the visible (400–700 nm) and near-infrared (700–1300 nm) wavelength regions, the reflectance contrast between soils and residues changes as soil moisture changes and as residues weather and decompose. In these wavelength regions, soils and residues generally lack unique spectral signatures. Residues may be brighter or darker than a given soil, even within a single field (Aase and Tanaka, 1991; Daughtry et al., 1995a; Gausman et al., 1975; McMurtrey et al., 1993; Stoner et al., 1980). Thus, visible and near-infrared reflectance techniques to quantify crop residue cover need frequent calibrations or adjustments to discriminate accurately between soil and crop residues in the field.

In the shortwave infrared (1300–2400 nm) wavelength region, absorption features associated with lignin, cellulose, or various minerals may be useful for discriminating residues from soils (Daughtry et al., 1995b; Clark et al., 1990; Elvidge, 1990). However, water absorption dominates the spectral properties in the shortwave infrared region, so that changes in moisture content of the soil and reside will likely affect discrimination.

Fluorescence

McMurtrey et al. (1993) first proposed that the blue-green fluorescence induced by a nitrogen laser, emitting at 337 nm, could be used to discriminate between crop residues and soils. The blue-green fluorescence intensities of the crop residues were 2–10 times greater than the fluorescence of the soils. In subsequent work, Daughtry et al. (1995a) showed that the UV-induced fluorescence of crop residues was a broad band phenomenon with an emission maximum within the 420–520 nm band for an excitation band of 350–400 nm. Most soils have low intensity emissions over the same wavelength range. Compounds that fluoresce when excited with longwave ultraviolet (300–400 nm) are abundant in plants, but scarce in soils. The origin of the blue-green fluorescence of plants is not completely understood, but is probably the sum of the fluorescence of riboflavin, lignin,

lignin precursors (e.g., ferulic acid, caffeic acid, and cummaric acid) and phenolic and polyphenolic compounds (Chappelle et al., 1991; Goulas et al., 1991; Lichtenthaler et al., 1991; Lundquist et al., 1978).

Daughtry et al. (1995a; 1996) measured the fluorescence of wet and dry soils as well as those of recently harvested and weathered residues of several crops. As the crop residues decomposed, their fluorescence values decreased and eventually approached the fluorescence of the soils. Moisture reduced the fluorescence, but the relative difference in fluorescence between crop residues and soil remained fairly constant. They concluded that fluorescence techniques were better suited for discriminating soils and residues than reflectance techniques.

Most of the previous research has used non-imaging techniques to measure fluorescence. However, advances in low-light imaging technology make it possible to capture fluorescence images. For example, Albers et al. (1995) described a laser-induced fluorescence imaging system developed by the U.S. Department of Energy (DoE) for airborne and ground-based detection, characterization, and monitoring of contaminants in the environment. This system consisted of a laser for the excitation source and an intensified charged-coupled device camera to collect optically filtered images. Images of crop residue fluorescence could provide qualitative as well as quantitative information about the amount of residue cover present. Our objective was to evaluate the concept of fluorescence imaging to quantify crop residue cover.

MATERIALS AND METHODS

Soils and Crop Residues

Topsoil samples from six U.S. cropland soils, selected to span the range of reflectance expected in most agricultural fields, are listed in Table 1. Sixteen scenes were created using the six soils as backgrounds and by adding various amounts of soybean residue. The soybean residue, collected 8 months after harvest, was mottled with dark-colored areas caused by microbial colonization and was selected as representative of crop residues that fluoresce moderately (Daughtry et al., 1995a). We determined the area viewed by the video camera and added sufficient soybean residue to provide 26.2–46.5% residue cover (Table 2). The projected area of each sample of soybean residue was measured five times with an area meter (LI-3100,[1] Licor, Inc., Lincoln, Nebraska, USA). The coefficient of variation for the mean projected area of all residue samples was 0.8%. The soybean residue was carefully placed on each soil with no overlapping

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[1] Company and trade names are given for the benefit of the reader and do not imply any endorsement of the product or company by the U.S. Department of Agriculture.

Table 1. Soil Names and Sources of the Topsoils Used in This Study

Soil Series	Location	Classification
Barnes	Morris, Minnesota	Coarse-loamy, mixed Udic Haploboroll
Cecil	Watkinsville, Georgia	Clayey, kaolinitic, thermic Typic Hapludult
Cordorus	Beltsville, Maryland	Fine-loamy, mixed, mesic, Fluvaquentic Dystrochrept
Houston Black Clay	Temple, Texas	Fine, montmorillonitic, thermic Udic Pellustert
Othello	Salisbury, Maryland	Fine-silty, mixed mesic Typic Ochraquult
Portneuf	Twin Falls, Idaho	Coarse-silty, mixed, mesic Durixerollic Calciorthid

pieces. Thus, the projected area, measured with the area meter, should accurately represent the residue cover in each scene.

Reflectance Factors

Relectance spectra of the bare soils and the soybean residue were acquired outdoors using a spectroradiometer (Model SE590, Spectron Engineering, Denver, Colorado, USA) with 1° field of view. The instrument was positioned with a nadir view at 0.7 m above the 0.45 m square sample trays. The diameter of the field of view was about 12 mm, which was slightly larger than the diameter of the soybean stems. Twenty locations per sample tray were measured. After the spectra of air-dried samples were acquired, the samples were thoroughly wetted with water and allowed to drain, and a second set of spectra was acquired. Data were acquired under clear sky conditions and were referenced to a Spectralon panel (Labsphere Inc., North Sutton, New Hampshire, USA).

Multispectral Video Images

Video images were acquired in the laboratory with a Xybion Intensified Multispectral Camera (Model 201, Xybion Electronics Corp., Cedar Knoll, New Jersey, USA). The camera employed a micro-channel-plate intensifier to amplify the images up to 15,000 times. A filter wheel, located in front of the intensified camera assembly, contained the following bandpass interference filters: 453–488 nm, 535–570 nm, 650–685 nm, 735–750 nm, 775–795 nm, and 840–870 nm. Although the 453–488 nm band was not optimal for measuring the broad band fluorescence of crop residues (Daughtry et al., 1995a), it was satisfactory for this proof-of-concept demonstration. For the fluorescence images, we operated the camera in the locked filter mode and integrated the signal over 6–120 video fields (0.1–2.0 s) depending on scene brightness. Video images were acquired using the Xybion Image Capture and Analysis System (XICAS) hardware and software on a personal microcomputer.

Table 2. Classification Results of Fluorescence Images of Soybean Residue on Various Soils[a]

Soil Series	Relative Moisture	Threshold Value[b]	Fluor. Cover (%)	Meas. Cover (%)	Error[c] (%)
Barnes	Dry	5	26.5	26.4	0.1
	Wet	7	27.3	26.4	0.9
Cecil	Dry	5	26.6	26.2	0.4
	Wet	3	26.7	26.2	0.5
Codorus	Dry	7	28.1	26.4	1.7
	Wet	5	28.0	26.4	1.6
Houston-1	Dry	5	26.0	26.2	−0.2
	Wet	5	26.7	26.2	0.5
Houston-2	Dry	5	48.4	46.5	1.9
	Wet	5	47.1	46.5	0.6
Othello	Dry	5	26.7	26.2	0.5
	Wet	4	26.8	26.2	0.6
Portneuf-1	Dry	5	26.5	26.2	0.3
	Wet	5	26.7	26.2	0.5
Portneuf-2	Dry	7	49.3	46.5	2.8
	Wet	7	48.7	46.5	2.2
Mean (S.D.)					0.9 (0.8)

[a] The projected area of the soybean residue was measured with an area meter.
[b] Pixel values greater than the threshold value are classified as crop residue. Pixels less than or equal to the threshold are classified as soil. Threshold value was set by iteratively classifying and viewing each image until most of the pieces of residue were correctly classified.
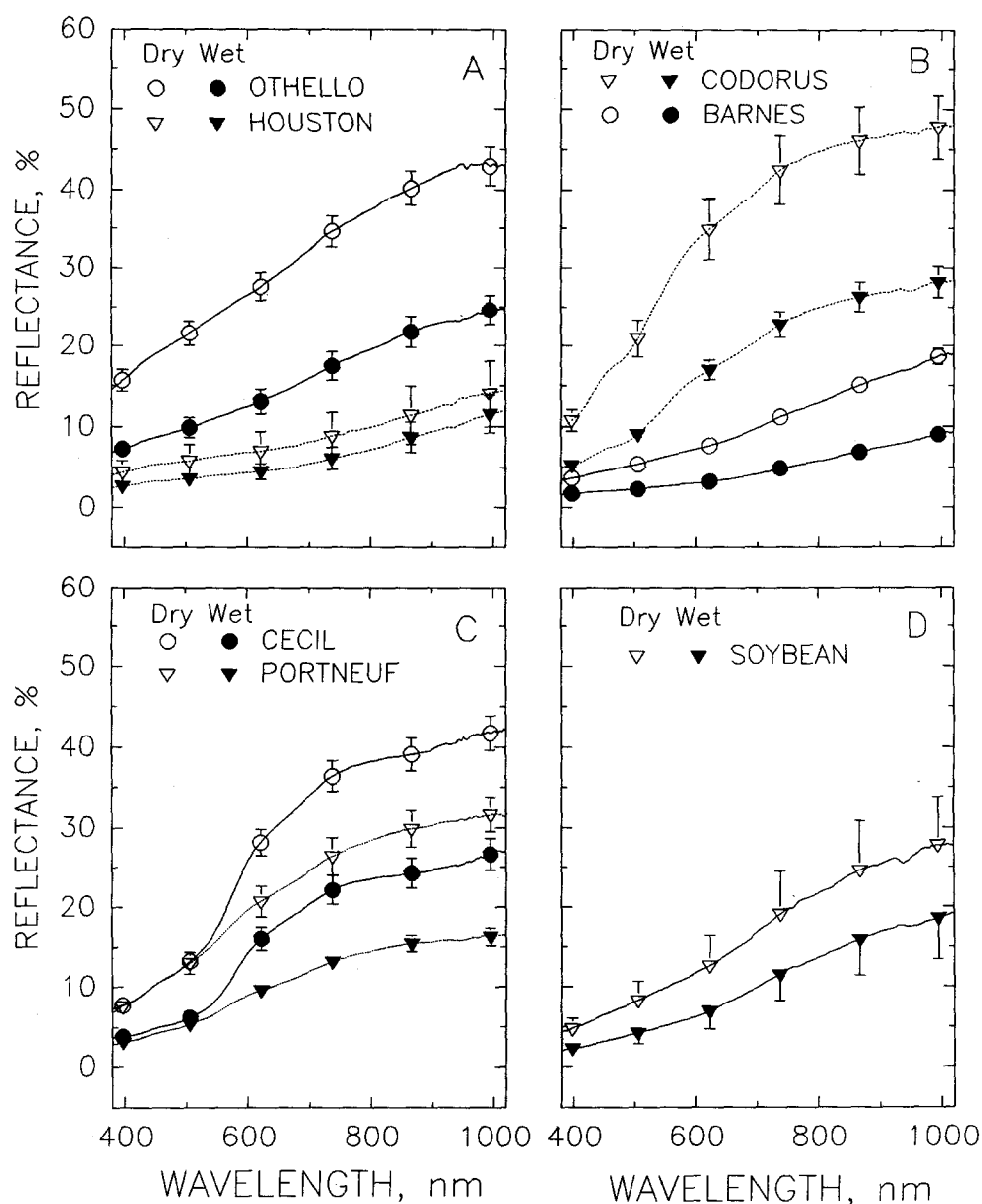[c] Error=residue cover estimated by fluorescence minus measured residue cover.

Figure 1. Dry and wet reflectance spectra for the six soils and the soybean residue. In each case, the upper spectrum is for the dry sample and the lower spectrum is for the wet sample. The error bars represent ±1 standard deviation at selected wavelengths.

The video camera equipped with a 25-mm Navitron lens was mounted on a camera copy stand 0.4 m above the sample surface. The full image format of the camera was 752×480 lines. The area of interest within each frame was 714×413 pixels, which corresponded to 0.092 m² (0.23×0.40 m) or about 0.32 mm²/pixel. Thus, the video pixels were much smaller than the typical 4–8 mm width of the soybean residue.

Florescence images were acquired in the lab by illuminating each scene (soybean residue+soil) with only ultraviolet radiation from four 12-V, 6-W, longwave UV lamps (Model ML49, UVP, Inc., San Gabriel, California, USA). The UV lamps were arranged in a square pattern

0.3 m above the soil surface and provided uniform UV radiation with a peak intensity at 365 nm. Radiation from the UV lamps was filtered through Schott UG-1 glass to minimize radiation from the lamps with wavelengths greater than 400 nm that would interfere with measurements of fluorescence. The reflectance images were acquired by illuminating each scene with only visible–near-infrared radiation from two 300-W quartz halogen lamps. For both the fluorescence and the reflectance images, stray light sources in the lab were either turned off or screened from view.

After acquiring images of the soybean residue on the dry soil, we thoroughly wetted the soil and residues with

water and acquired another set of images. Additional images of bare soil (0% cover) and crop residue (100% cover) were also acquired.

RESULTS AND DISCUSSION

Reflectance Factors

Reflectance factors of the dry and wet soils and soybean residue are presented in Figure 1. The shapes of the reflectance spectra for the soils and reside are remarkably similar, as other researchers have noted (e.g., Aase and Tanaka, 1991; Gausman et al., 1975; Daughtry et al., 1995a). Over the 400–1000 nm wavelength region, the reflectance factors of both soil and reside increased monotonically with wavelength with no unique spectral signature. The reflectance factors of the soybean residue and the various soils overlap considerably depending on soil moisture conditions so that significant misclassification is likely. For example, both dry Othello (Fig. 1a) and dry Codorus (Fig. 1b) soils were brighter at all wavelengths than the dry soybean residue (Fig. 1d); however, when wet, both soils had reflectance spectra very similar to that of the soybean residue.
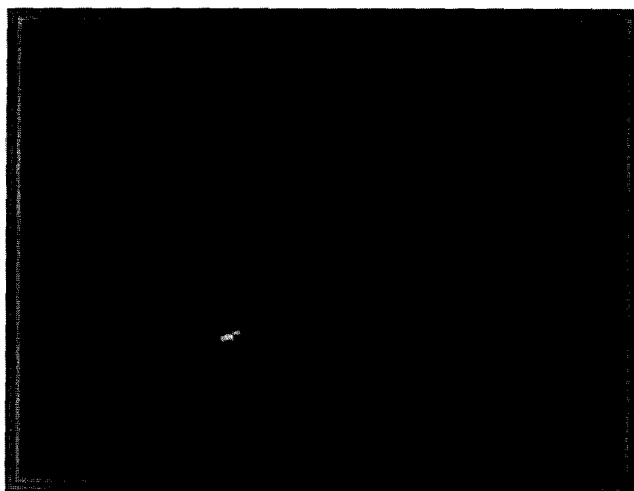
Fluorescence Images

In the fluorescence images, the soybean residue is brighter than the dry Othello (Fig. 2a) and the wet Houston (Fig. 2b). These observations agree with the previous results (Daughtry et al., 1995a; 1996; McMurtrey et al., 1993) that show crop residues fluoresce much greater than soils. The brightest areas in the image correspond to portions of the soybean stems that had the least evidence of microbial colonization. Likewise the darkest areas, that is, lowest fluorescence intensity, of the soybean stems correspond to areas with the most microbial colonization.

The histograms of the fluorescence images further confirm this observation. Greater than 99% of the bare soil pixels in the fluorescence images of Figure 2 had values of 0 (Figs. 3a and 3d). Some of the highest values in the soil images appear to be small bits of residue in the soil, perhaps from previous crops. The brightness values of the soybean residue spanned the 8-bit brightness range; however, greater than 98% of the soybean residue pixels had brightness values ⩾1 (Figs. 3b and 3e). Some of the lowest values in the residue images are from the dark spots on the residue or from shaded areas between pieces of residue, which were not adequately illuminated by the UV lamps. Both of the histograms of the soil+residue images are strongly positively skewed (Figs. 3c and 3f).

Although the histograms of the soil+residue images overlap, discrimination of soil from residue is possible. For this simple two-class model (soil vs. residue), we classified pixels with brightness values ⩾5 as soybean residue and displayed them as white in Figure 4. The

a

b

Figure 2. Video images of the blue fluorescence (452–488 nm) images of a) 26.2% soybean residue cover on dry Othello soil and b) 46.5% residue cover on the wet Houston Black Clay soil.

remaining pixels in the image with a brightness value <5 were classified as soil and were displayed as black pixels in Figure 4. Using this simple two-class model, we estimated crop residue cover to within 1% on both soils. Inspection of the classification image clearly reveals that most of the residue is accurately represented. There were some noticeable errors of omission, where portions of a continuous stem were classified as soil, as well as some errors of commission, where small areas of soil were classified as residue. During a post-classification examination of the scene, we noticed some small pieces of plant material in the soil presumably remaining from the previous crop. In particular, the Barnes and the Houston soils had obvious small pieces of residue from previous crops. Therefore, the actual residue cover was slightly greater than expected for most of the soils examined (Table 2).
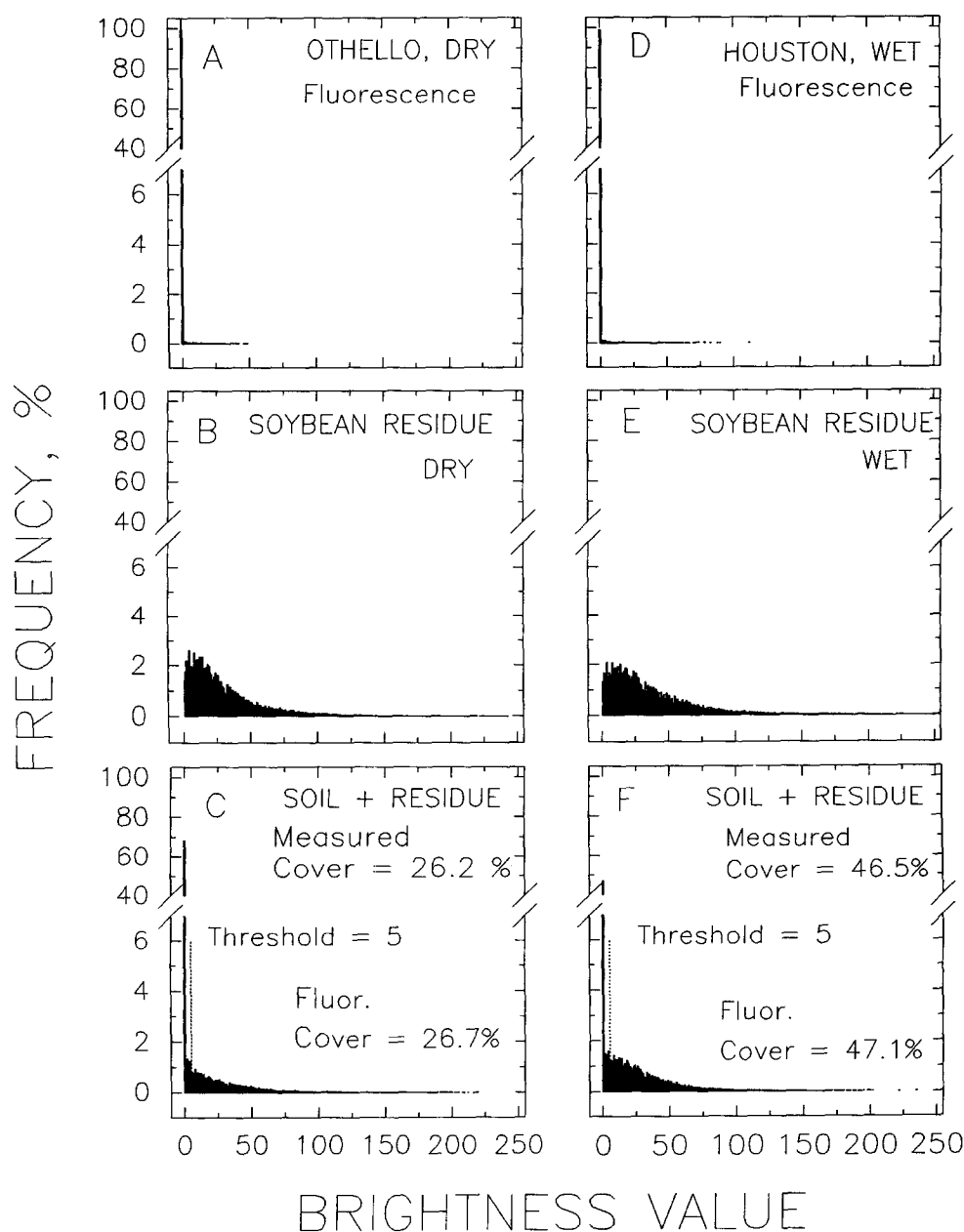
Figure 3. Histograms of the blue fluorescence (452–488 nm) images of a) dry Othello soil, b) dry soybean residue, c) 26.2% soybean residue cover on the Othello soil, d) wet Houston Black Clay soil, e) wet soybean residue, and f) 46.5% soybean residue cover on the Houston Black Clay soil. The horizontal axis is the brightness value (0–255) and the vertical axis is the percentage of the pixels with each brightness value. Pixels with values >5 were classified as residue and values ≤5 were classified as soil.

Table 2 shows the classification results for all soils. Moisture reduced the fluorescence of both the soil and residue, as Daughtry et al. (1995a) reported, but had little effect on classification accuracy. The threshold was set by iteratively classifying and viewing the images until most of the pieces of residue were correctly identified. In our experience, as one approached the correct classification threshold, the percent residue cover changed very little and small deviations (i.e., 3–5 brightness units)

from the optimum threshold had little effect on the overall result.

In these fluorescence images, we adjusted the exposure times to minimize overexposure, that is, we selected images with <0.2% saturated pixels (i.e., brightness values of 255 for this 8-bit camera). In the overexposed images, the crop residues appear much brighter and more visually appealing than correctly exposed images; however, the fluorescence emitted by the residue also illumi-

a
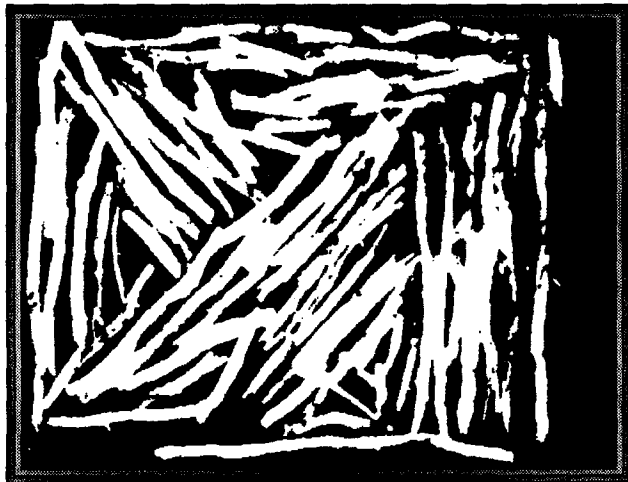
b

Figure 4. Classification of fluorescence images of soybean residue on a) dry Othello soil and b) wet Houston Black Clay soil. Crop residue is shown as white and the soil as black. Residue cover estimated from fluorescence is 26.7% compared to the measured value of 26.2% for the Othello soil and 47.1% compared to the measured value of 46.5% for the Houston Black Clay soil.

nated the soil and increased the brightness values of the soil pixels near pieces of residue. This resulted in broader, less distinct histograms of the soil+residue images, higher threshold values for discrimination, and generally poorer classification accuracies. Therefore, for best results, we recommend acquiring fluorescence images which exploit the dynamic range of the camera with only a few saturated pixels.

In summary, we have established that crop residue cover can be determined in the lab using images of crop residue fluorescence. Furthermore, fluorescence imaging techniques are less ambiguous for discriminating crop residues from soils than the reflectance imaging methods regardless of soil type or moisture status. The images

also provide a permanent record of the percent residue cover conditions in a field and can be reanalyzed as needed. Potential problems that must be addressed to implement the fluorescence technique in the field are (i) adequate excitation energy must be supplied to induce fluorescence and (ii) the fluorescence signal is small relative to normal, ambient sunlight. Techniques must be developed to either shield the system from sunlight or extract the fluorescence signal in the presence of ambient sunlight. The laser-induced fluorescence imaging system, described by Albers et al. (1995), addressed some of these problems and possibly could be configured to monitor crop residue cover. Nevertheless, additional development and testing is still required to produce a portable imaging system capable of quantifying crop residue cover in the field.

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